

ANALYTICAL APPROACH IN DECOM

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ABSTRACT

There are many papers on describing a LHP as an overall system, but few detail on the condenser section of a loop heat pipe. The DeCoM (Deepak Condenser Model) method utilizes user set initial parameters in-order to simulate a condenser by calculating the interactions between the fluid and the wall. Equations are derived for two sections of the condenser: a two-phase section and a subcooled (liquid) section. All Equations are based upon the conservation of energy theory, from which fluid temperature, and fluid quality values are solved. In order to solve for the heat transfer value, between fluid and the wall in two phase section, the Lockhart-Martinelli correlation method was implemented as a solution approach. For Liquid phase, the Reynolds number was used in-order to differentiate the flow state, from either turbulent or laminar, and Nusselt number was used to solve for the film coefficient. To represent these calculations for both sections a flow chart is presented in order to display the execution process of DeCoM. The benefit of DeCoM is that it is capable of performing preliminary analysis without requiring a license and without much of users' knowledge on condensers.

INTRODUCTION

DeCoM was developed in order to analyze the performance of the ATLAS (Advanced Topographic Laser Altimeter System) laser radiator with an embedded LHP (Loop Heat Pipe) condenser. In simple terms, the function of a condenser is to reject heat released by a fluid phase change. In order to fully understand how the phase change occurs under specific conditions inside the condenser, it's necessary to understand the performance of a condenser in theoretical terms. This paper will discuss how the conservation of energy is applied on a control volume, for a given condenser node, as well the correlation method to calculate the two phase heat transfer calculations of the thermal coefficient, h . The control volume analysis approach allows for any given condenser location (axially, along the condenser length) to be quantified. Equations derived for DeCoM are based on simplistic assumptions; simple energy balance equations, non changing mass flowrate equation, mass flowrate as a constant value, and the condenser as an independent loop heat pipe component. These simplifications limit the flexibility of DeCoM for use in generic thermal models, but can be very useful to the thermal analyst for rudimentary single LHP condenser computations. DeCoM's capabilities as well as its limitations and future work to improve the reliability of DeCoM are discussed in this paper.

DeCoM assumes a saturated vapor inlet at specific saturation temperature and calculates the thermodynamic state of the current node being analyzed. The fluid to wall temperature and the heat transfer convection coefficient, h ($\text{W}/\text{m}^2\text{K}$) is also calculated as part of the interactions. These results then interface with the thermal analysis software, such as SINDA, which calculates the condenser wall temperature and radiator temperature to which the condenser is attached. The outputs can be printed by the user in order to check the operation at each node of the condenser by simply modifying the “WRITE” statement in the condenser code. The inputs give the code a start, as well as behave as boundary conditions after which the code will calculate two-phase and liquid section heat transfer values, fluid temperatures, and fluid qualities.

CONDENSER OPERATION

A LHP consists of an evaporator (capillary pump), a compensation chamber, a heat exchanger (condenser), and the vapor & liquid transport lines. A LHP schematic is shown in Figure 1¹.

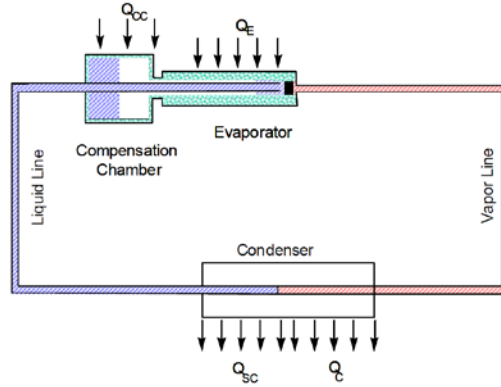


Figure 1: Loop Heat Pipe Schematic

In a LHP, the heat input (Q_E) conducted from the instrument to the evaporator vaporizes the liquid inside the evaporator. The vapor travels along the vapor line to the heat exchanger where it condenses back to liquid rejecting the heat; once all the heat has been rejected, the fluid turns to subcooled liquid and the fluid temperature decreases. As depicted in Figure 2, a portion of the heat exchanger needs to cool the condensed liquid below the loop saturation temperature before the liquid exits the heat exchanger². In Figure 2, the variable x is the quality, L_{2P} is the two phase length, L_L is the subcooled liquid length, and L_C is the overall condenser length. It's highly advised to incorporate subcooled length in order to maintain energy balance between evaporator heat leaks and subcooled heat.

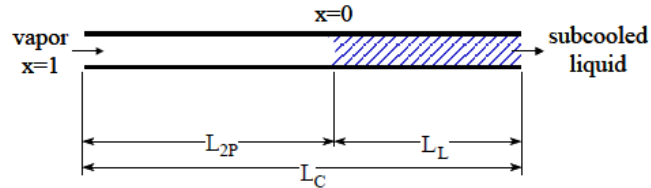


Figure 2: Heat Exchanger as Condenser and Subcooler

As previously described, a condenser is divided into two parts: a two phase section and a subcooled section. Within the two-phase section, heat is rejected to the sink through means of

conduction to the radiator. A condenser's capability to reject heat is directly influenced by the radiator design. If the radiator is not sized properly to reject heat that is sensed from the coupled component, then the condenser will stay as two phase fluid. When a condenser is fully two phase, this means that it has not rejected all the heat, and therefore it is an in-efficient design. This concludes that it is important to size the radiator after which the condenser can be implemented to reject all heat.

METHODOLOGY

A fluid state can be defined by any two unique thermodynamic properties, for e.g. temperature and pressure. Figure 3 shows the thermodynamic behavior of fluid in a single condenser line: fluid enters as superheated vapor; stays at saturation temperature until all heat has been rejected in the two phase region, and finally subcools below saturation temperature and exits the condenser.

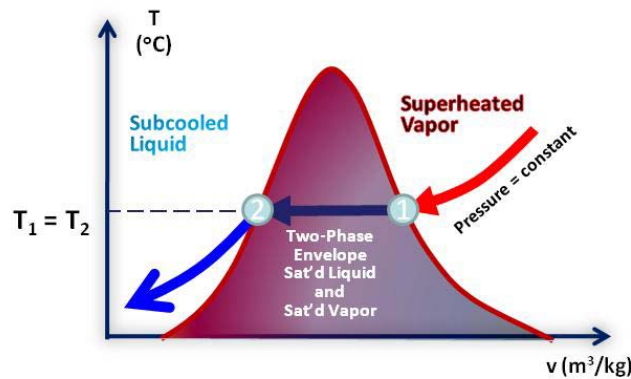


Figure 3: Temperature vs. Specific Volume thermodynamic plot

Parameters such as fluid quality, fluid temperature, mass flowrate and heat transfer convection coefficient between the fluid and the wall are all calculated through the described governing equations. The mass flowrate variable is crucial to calculating every other parameter. Using the heat source operating value and the fluid latent heat of vaporization, the mass flowrate can be estimated. In an actual loop heat pipe, the mass flowrate varies with each loop depending upon the heat leak between the compensation chamber and the evaporator. To take this heat leak into account, a 1% (empirically formulated value) reduction in total power has been applied within DeCoM.

CONSERVATION OF ENERGY ON A CONTROL VOLUME

The first calculation required in order to perform condenser analysis is the mass flow rate calculation. As mentioned earlier that mass flow-rate for this project was calculated using a constant value. In a loop heat pipe, the mass flow rate changes due to heat leaks from the evaporator or the compensation chamber, which this project applies an empirical value for. This empirical value of 1% is applied to the input power and the mass flow-rate equation is derived as follow: $\dot{m} = \frac{(Q_E - 0.01 * Q_E)}{\lambda}$ where Q_E is the input power and λ is the latent heat of vaporization at saturation temperature. Conservation of energy applied to a control volume around a fluid

“node” can be used to derive the equations for the state of the fluid within the control volume in a system with mass flow. Conservation of energy can be applied to any closed system, in which total heat entering the system must be equal to the total heat leaving the system (as shown in Figure 4). The heat flow for the given control volume can help derive the equations to calculate the fluid parameters as described in Figure 5. The known parameters are: T_{fi} , T_{wi} , x_{in} , $G_{2\phi}$ (x_{in}), $Q_{2\phi}$ ($G_{2\phi}$, T_{wi}). The values for T_{fi} and T_{wi} are passed in as initial values which are used to calculate the next fluid node values. The same T_f and T_w variables along with fluid to wall interaction values are returned for next node calculation. The quality is assumed to be 1 at the inlet condition. Figure 10 shows the subroutine template describing the inputs and outputs for DeCoM’s control volume analysis approach.

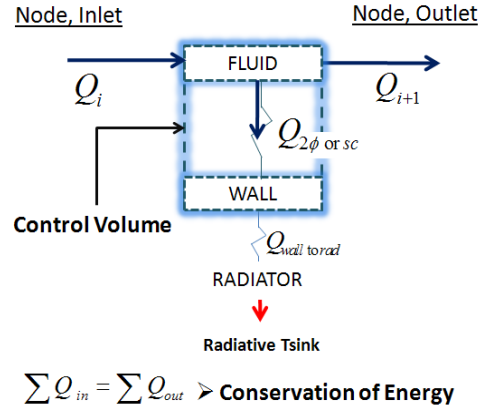


Figure 4: Control Volume on a condenser node

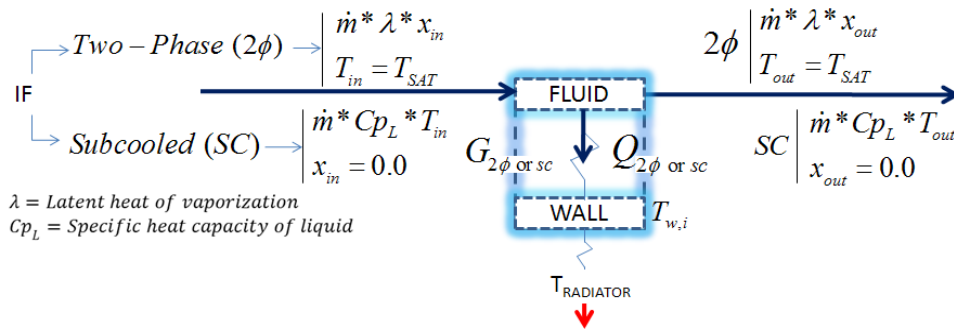


Figure 5: Equation flow chart on a condenser node

Figure 5 shows that the condenser equations are categorized as either two-phase (2 Φ) or subcooled (SC). The equations and energy balance for two-phase section are briefly described in Figure 6. Equation 2 is used to determine the quality of the fluid for the next fluid node in two-phase flow. If the quality is between zero and one the fluid has a mix of vapor and liquid (two-phase) and if the quality is less than zero the fluid is single phase (SC liquid). Estimating the heat transfer convection coefficient, h (W/m²K), from empirical correlations and knowing the inlet state leaves the x_{out} as the only unknown (x_{out} from Equation 2).

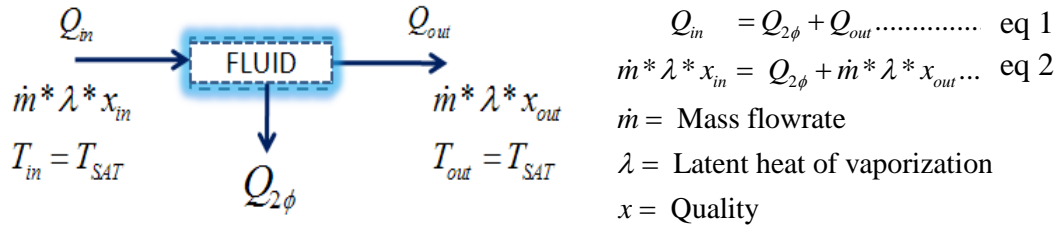


Figure 6: 2Φ energy transfer

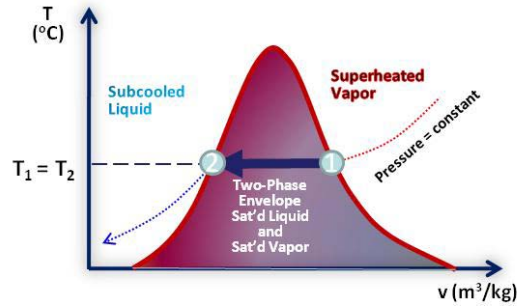


Figure 7: 2Φ thermodynamic state

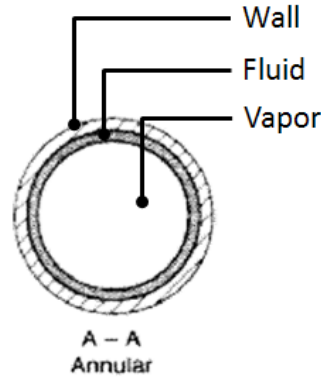


Figure 8: Annular flow regime

2 Φ HEAT TRANSFER CALCULATION

The change in quality is directly related to the convection between the fluid and the wall $h_{2\phi}$ and can be calculated through empirical values or correlation methods. The fluid thermodynamic state is displayed in Figure 7, and shows that in the two phase region the temperature is constant (at saturation temperature). For this section, the flow regimes can vary depending on the quality, the Reynolds number, and the condensation rate. Several studies on two-phase flow condensation rate have developed correlations using graphical methods, such as the Lockhart-Martinelli method³. For reference to Lockhart Martinelli correlation equation please refer to References section of this paper and reference number 3. One thing to notice about the Lockhart-Martinelli correlation is that it assumes an annular flow regime for the entire two-phase section (as shown in Figure 8). Vapor at the center portion of the condenser and liquid on the film within the wall.

The Lockhart-Martinelli correlation was used in order to calculate h (W/m^2K), the heat transfer convection coefficient. The variable “X” in the $Q_{2\phi}$ equation is the Lockhart-Martinelli parameter which the two phase multiplier (Φ) is dependent upon. DeCoM uses this correlation relationship between X and Φ to calculate $G_{2\phi}$. This heat transfer value is then used to calculate the fluid quality of the next node. If equation 2 and $Q_{2\phi}$ equations are combined then the results would be: $\dot{m} * \lambda * x_{in} = G_{2\phi} * \Delta T_{f-w} + \dot{m} * \lambda * x_{out}$, where $G_{2\phi}$ is represented as a function of X solved in equations below. The variable x_{out} can be solved as shown in the following equation: $x_{out} = x_{in} - \frac{Q_{2\phi}}{\dot{m} * \lambda}$, where x_{out} is the only unknown. The $Q_{2\phi}$, $G_{2\phi}$ and X variable calculations are performed as following:

$$Q_{2\phi} = (\phi)^{\frac{1}{2}} * h_l * A_s * \Delta T_{f-w} \quad G_{2\phi} = ((1 + 20 * X + X^2)^{\frac{1}{2}} * h_l * A_s)$$

$$\phi = 1 + 20 * X + X^2 \quad X = \left[\frac{f_{w,v}}{f_{w,l}} \right]^{\frac{1}{2}} \left[\frac{\rho_l}{\rho_v} \right]^{\frac{1}{2}} \frac{x}{1-x}$$

Refer to nomenclature section for variables name

SUBCOOLED HEAT TRANSFER CALCULATION

The h value calculation for the subcooled section is trivial compared to the two-phase section. The first step is to calculate the Reynolds number, which will identify the flow as laminar or turbulent for the proper estimation of the Nu. The equation flow chart, Figure 9, describes the SC section heat transfer calculation.

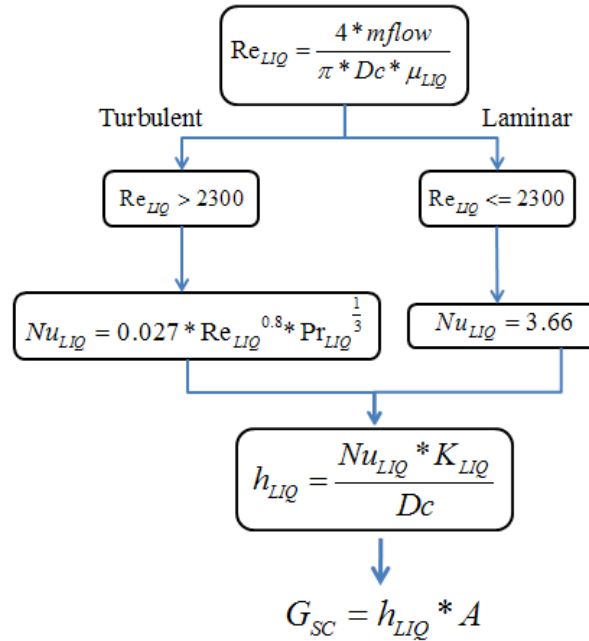


Figure 9: Subcooled section flow chart of equation

From Figure 9, the variable G_{SC} is used to calculate the temperature of the working fluid leaving the node. Combining the G_{SC} known value and energy balance equation for subcooled section from Figure 5 the result would be following: $G_{SC} * T_{fluid} = \dot{m} * C_p * (T_{in} - T_{out}) + G_{SC} * T_{wall}$, where G_{SC} is represented as a function of h_{liq} solved in Figure 9. T_{out} is solved using

the mean effective fluid temperature as function of G_{SC} and wall temperature. Solving for T_{fi} results in $T_{fi} = T_{wi} - \frac{\dot{m} * C_p * (T_{in} - T_{out})}{G_{SC}(i)}$

DEVELOPMENT OF DECOM COMPUTER CODE

DeCoM was developed using FORTRAN to model the condenser behavior based on the equations presented in pervious sections. DeCoM only calculates the behavior of a single loop heat pipe condenser. Integration of DeCoM with a thermal analysis tool such as SINDA allows the prediction of the 2Φ behavior as part of the thermal model. EXCEL and other implementations that are compared to DeCoM are described in the paper “DeCoM Validation”⁴. It was developed to perform calculations for transient as well as steady state analysis. The benefits of DeCoM are that it can be used with Thermal Desktop/SINDA in order to map temperatures in finite element models, print fluid parameters depending on the user’s request, as well as use the parameters to calculate fluid temperatures, quality and fluid properties. DeCoM does not require a license to operate and therefore is easily distributable. The input of this code is done under the variables 1 logic block of SINDA so that DeCoM can be executed at every time-step. The input variables and the subroutine template are both displayed in Figure 10.

SUBROUTINE CONDENSER (D, L, NE, FLNAME, POWER, TSAT, TIN, XIN,
TW, TF, XF, GF, X1,X2,X3,X4)

➤ Input Parameters

- D – Diameter of Condenser , m
- L – Overall Length of the Condenser , m
- NE – Number of fluid nodes
- FLNAME – Fluid Name
- Power – Evaporator power , W
- TSAT – Saturation Temperature , K
- XIN – Condenser Inlet Quality, (Assumed to be 1.0)
- TW – Array of Wall Temperature , K

➤ Output Parameters

- TF - Array of Fluid Temperature , K
- XF - Array of Fluid Quality
- GF - Array of Fluid to Wall Heat Transfer value , W/K
- X1,X2,X3,X4- Array of User Specified Outputs. (Requires more editing)

- User calls the above *Subroutine* from a Thermal Analyzer to read in Condenser input data and set initial conditions.
 - Subroutine calculates the Fluid Properties, temperatures and the fluid to wall heat transfer value.

Figure 10: DeCoM Subroutine Template

Figure 11 details the calculations steps of DeCoM for both two-phase and subcooled. DeCoM requires further development for it to become more flexible for users. Future work takes into account the user specific needs such as a correlation method other than Lockhart-Martinelli, validate the method with multiple LHP test data to increase reliability, include various fluid options other than ammonia, and incorporate a better implementation within thermal analysis software such as SINDA.

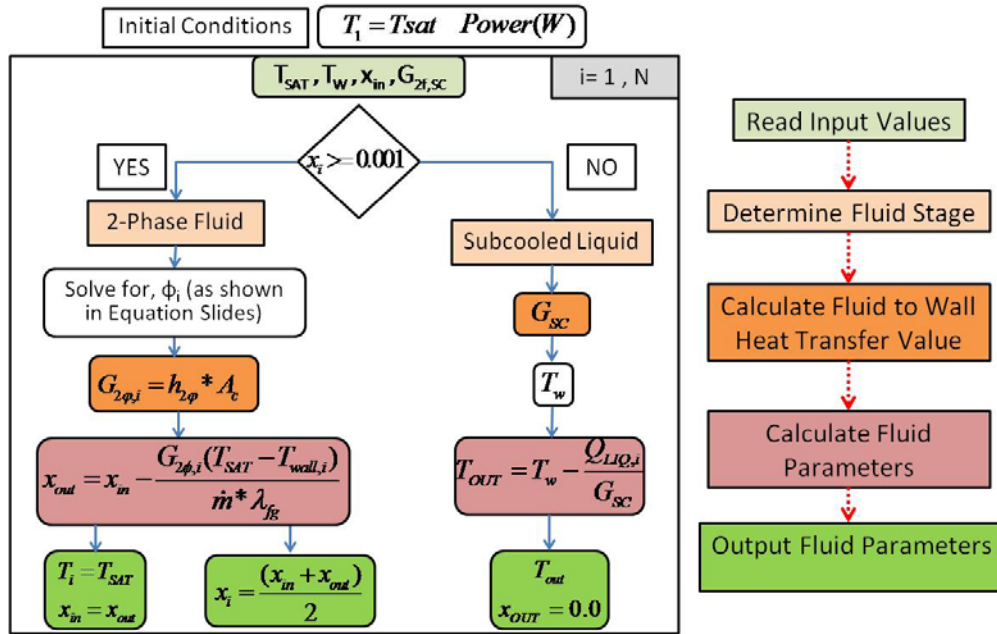


Figure 11: DeCoM calculations flow chart

SUMMARY

In summary, DeCoM has been presented as an alternative to the rest of the loop heat pipe condenser modeling software's. Interactions between the loop heat pipe components and the condenser have not been taken into account as this approach only analyzes the condenser for preliminary analysis. As mentioned in the "Methodology" section that mass flowrate was assumed to be a constant value with an empirical heat leak percentage taken into account. This is one of the factors that limit the robustness of DeCoM as it does not interact with other loop heat pipe components. The next step was to derive equations for a given condenser fluid node by applying two theories. One theory was the control volume analysis and the second was the conservation of energy. By combination of these two theories and correlation equations (for two phase section of the condenser) the fluid to wall interactions can be computed. The correlation method implemented for the two phase section was Lockhart-Martinelli correlation, since this isn't the only correlation available, in next DeCoM update there will be an effort to take other correlations into account. Currently DeCoM is under construction to improve its reliability and flexibility so that it's approachable by a novice. DeCoM in full function can be found in the "DeCoM Validation"⁴ paper.

ACKNOWLEDGEMENT

I would like to thank, Hume Peabody and Matthew Garrison for their undivided attention and monumental support: Also, Thank You to Dr. Jentung Ku, Tamara Oconnell, and the entire GSFC Thermal Engineering Branch supporting me and making this project possible.

CONTACT

For more information on DeCoM code or the development of analytical methods for modeling simple two-phase heat transfer LHP condensers please contact Deepak Patel at Deepak.Patel@nasa.gov or (301)-286-1549.

NOMENCLATURE

μ :	Dynamic viscosity, kg/m*sec
2Φ :	Two Phase
A_s :	Heat transfer surface area, m ²
ATLAS :	Advanced Topographic Laser Altimeter
CC :	Compensation Chamber
C_p :	Specific heat capacity of liquid, J/kg*K
DeCoM :	Deepak Condenser Model
FLUINT :	Fluid Integrator
f_{w,l} :	Wall friction factor, liquid phase
f_{w,v} :	Wall friction factor, vapor phase
G_{2Φ} :	Conduction in two phase, between the fluid and the wall, W/K
GLAS :	Geoscience Laser Altimeter System
h :	Heat transfer convection coefficient, W/m ² K
h_l :	Heat transfer convection coefficient for liquid, W/m ² K
ICESat-II :	Ice Cloud Elevation Satellite II
LHP :	Loop Heat Pipe
LM :	Lockhart-Martinelli
mflow :	mass flowrate, kg/sec
°C :	Degree Celsius
Q :	Heat load, W
Q_{EVAP-AMB} :	Evaporator to Ambient heat, W
Q_{HL} :	Heat leak from CC to Evaporator, W
Q_{SC} :	Subcooled section heat, W
SBIR :	Small Business Innovation Research
SC :	Subcooled
SINDA :	Systems Integrated Numerical Differencing Analyzer
STOP :	Structural Thermal & Optical
TD :	Thermal Desktop
W :	Watts, W
X :	Lockhart-Martinelli parameter
x :	quality
ΔT :	Temperature difference, °C
λ :	Latent heat of vaporization, J/kg
ρ_v, ρ_l :	Vapor/Liquid density, kg/m ³
Φ :	Lockhart-Martinelli Two phase multiplier

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- ¹ Jentung Ku, Triem Hoang, and Tamara O'Connell.: Mathematical Modeling of a Miniature Loop Heat Pipe With Two Evaporators and Two Condensers, ASME Conf. Proc. 2009, 483 (2009), DOI:10.1115/HT2009-88243
- ² Triem T. Hoang and Jentung Ku.: Heat and Mass Transfer in Loop Heat Pipes, ASME Conf. Proc. 2003, 485 (2003), DOI:10.1115/HT2003-47366
- ³ Lockhart, R.W.; Martinelli, R.C.: Proposed correlation data for isothermal two-phase, Two-component flow in pipes. Chem. Eng. Prog. 45 (1949) 38–48
- ⁴ Deepak P.: DeCoM Validation, TFAWS 2011 Conference



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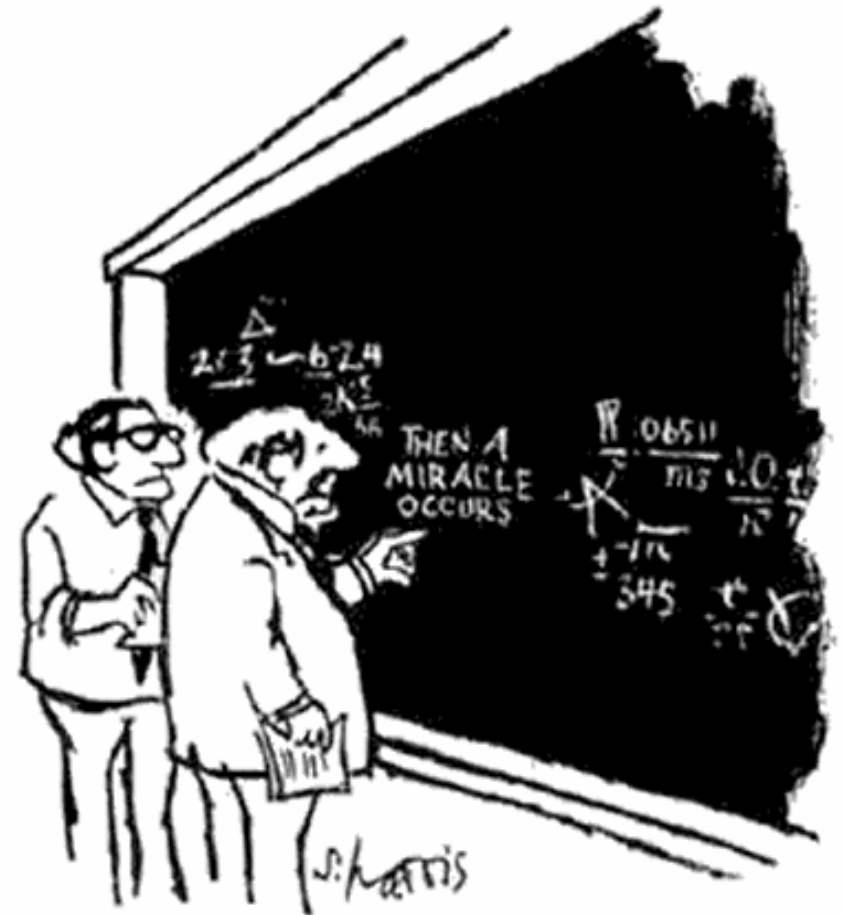
- **Hume Peabody**
- **Matt Garrison**
- **Dr. Jentung Ku**
- **Tamara O'Connell**
- **Thermal Engineering Branch at Goddard Space Flight Center**



Outline



- Introduction
- Governing Equations
- Develop 1D Computer Code
 - DeCoM
- Conclusion
 - Summary



"I THINK YOU SHOULD BE MORE EXPLICIT
HERE IN STEP TWO."

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Introduction: Purpose



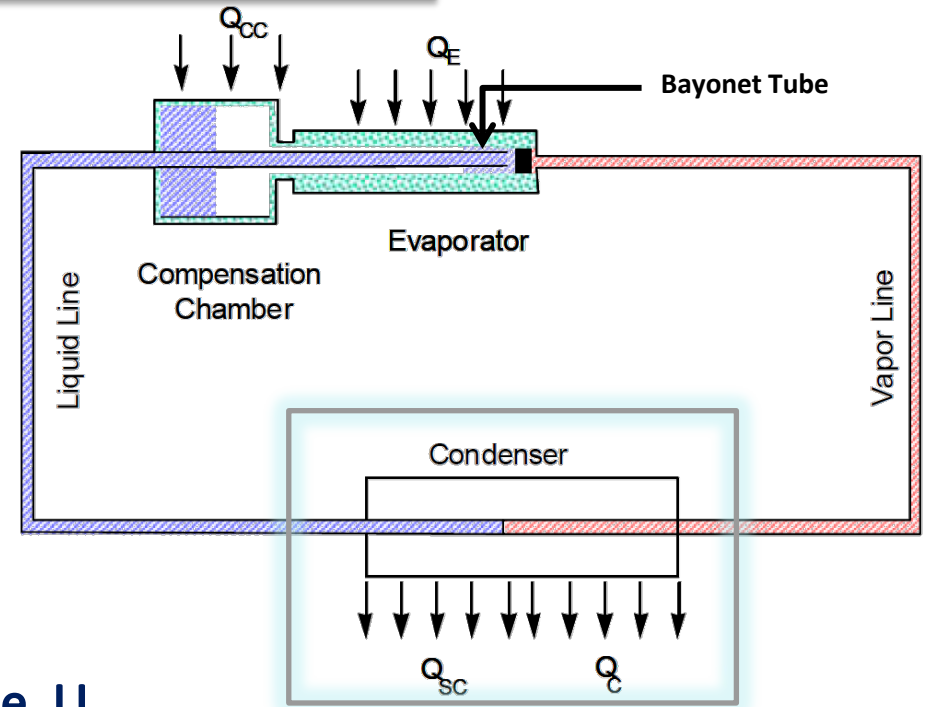
- **Purpose**



- To develop a model which efficiently and accurately simulates LHP Condenser
- Understand basic principles of two-phase flow
 - Correlation method for two-phase convection value
 - Governing equations to obtain quality change



Introduction: Introduction to LHP



- **Compensation Chamber, Q_{cc}**
 - Excess fluid is stored here, from which the LHP can increase its performance by accessing or storing the excess fluid.
- **Evaporator, Q_e**
 - Liquid from the bayonet is flown into the wick where it is converted to vapor, from the heat that is conducted from the instrument.
- **Vapor Line**
 - Vapor from evaporator is transferred to the condenser, adiabatically.

- **Liquid Line, LL**
 - Subcooled liquid from the condenser is returned to the evaporator.
- **Condenser – Q_c (Condenser), Q_{sc} (Subcooled)**
 - Q_c is the amount of heat rejected when the fluid is in two-phase, and Q_{sc} is for condensed Subcooled liquid section (1-phase fluid).

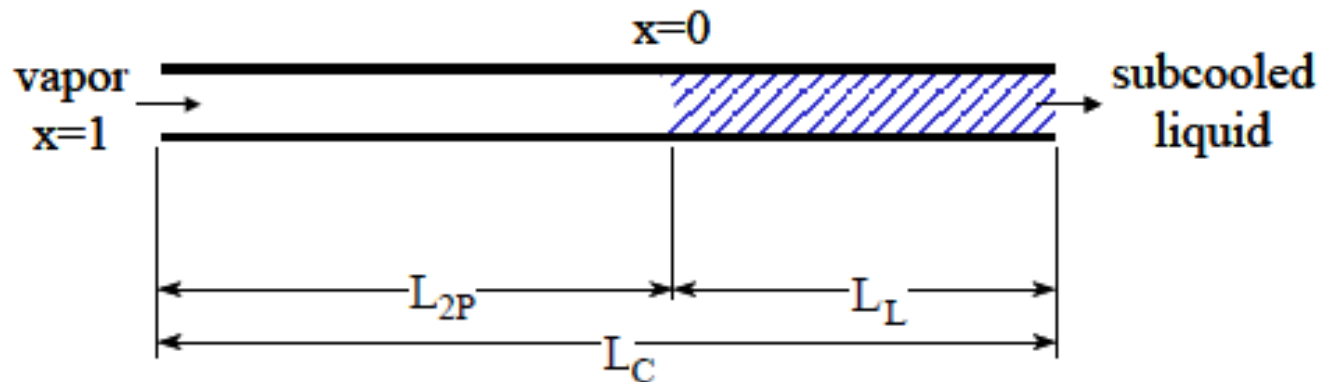


Introduction: Condenser Basics



- **Condenser:**

- Vapor generated travels from vapor transport line and enters the heat exchanger (condenser).
- Vapor enters as saturated vapor and phase change occurs, after which it is condensed to liquid.



Condenser and Subcooler



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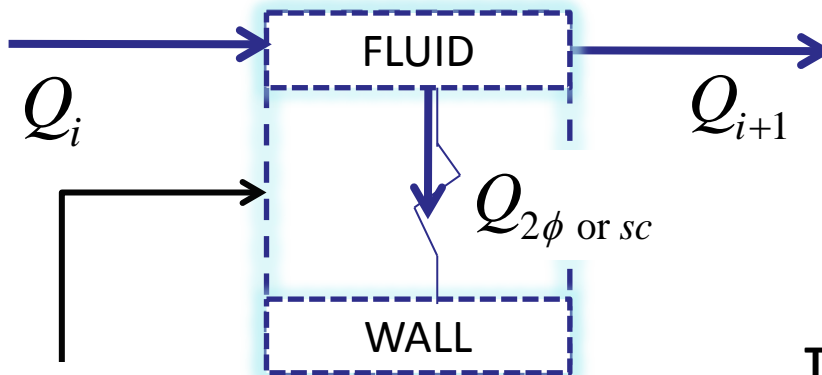


Governing Equations: Control Volume Analysis



Node, Inlet

Node, Outlet

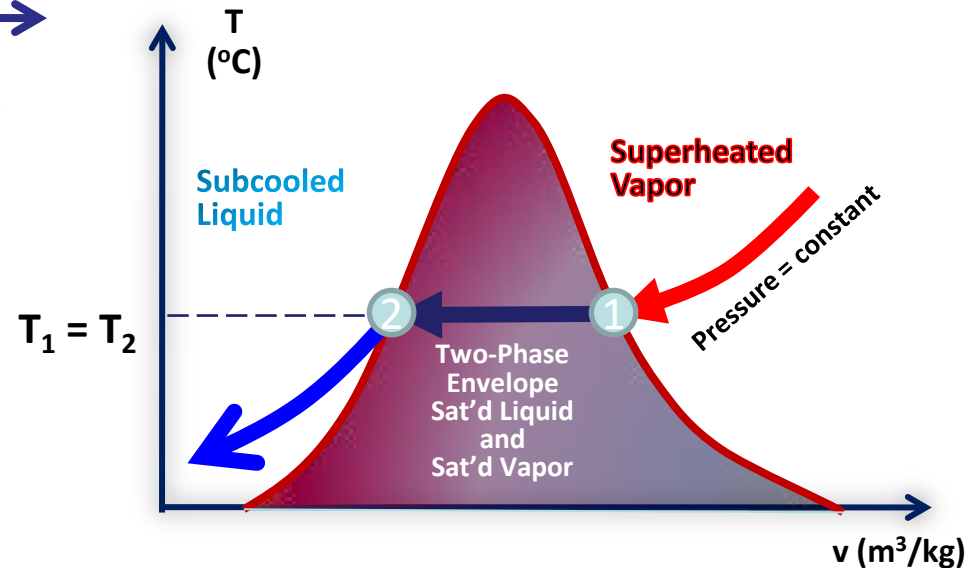


Control Volume
for which
Equations are
formulated

RADIATOR
↓
Radiative T_{sink}

$$\sum Q_{in} = \sum Q_{out} \rightarrow \text{Conservation of Energy}$$

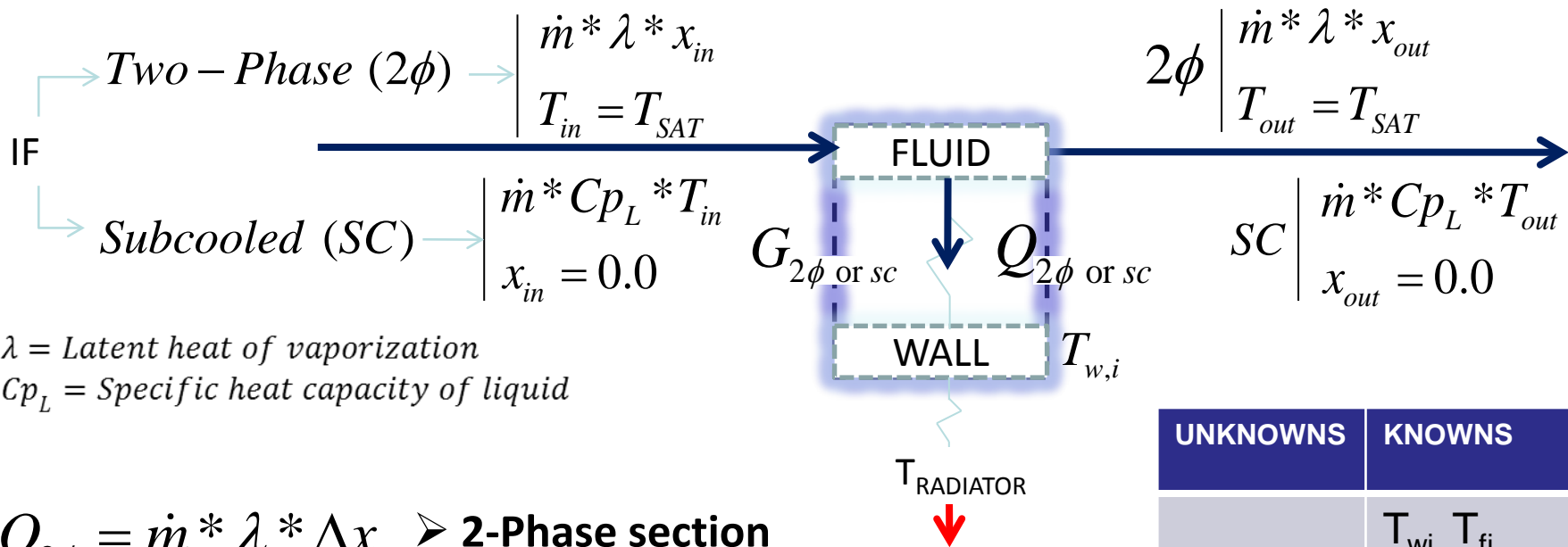
- Condenser source code is based on the Conservation of Energy equation. Applied on each node.



- The thermodynamic plot above describes the regions (arrows) that the equations are derived for.
- A fluid is defined by its any two thermodynamic property (e.g. temperature and pressure)



Governing Equations: Control Volume Analysis

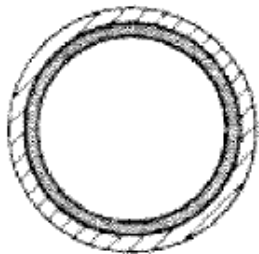
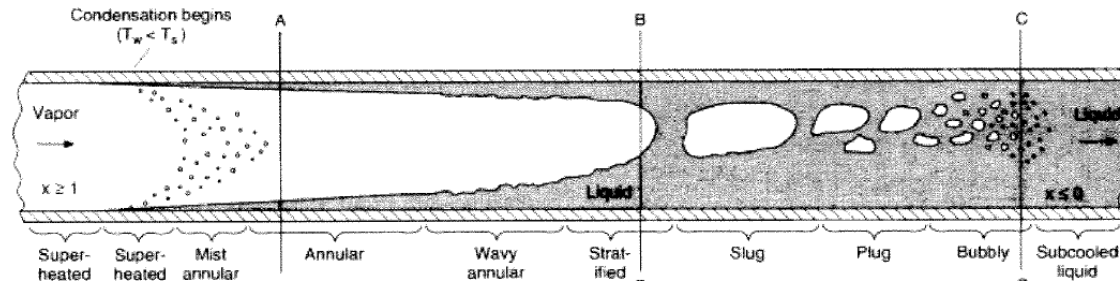


UNKNOWN	KNOWN
x_{out} if 2ϕ	T_{wi}, T_{fi} x_{in} $G_{2\phi}(x_{in})$ $Q_{2\phi}(G_{2\phi}, T_{wi})$
T_{OUT} if SC	T_{wi} T_{IN} G_{SC} $Q_{SC}(G_{SC}, T_{wi})$

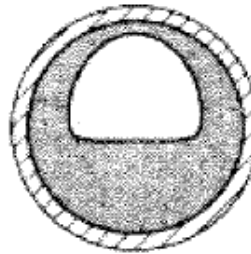
- $Q_{2\phi} = \dot{m} * \lambda * \Delta x \rightarrow$ **2-Phase section**
- $Q_{sc} = \dot{m} * C_{p_l} * \Delta T \rightarrow$ **Subcooled section**
- Inlet conditions are known
- Equations can vary depending upon the state of the fluid (2φ or SC), as shown above.
- **Lockhart-Martinelli** equations are used to solve for the $G_{2\phi}$ value.



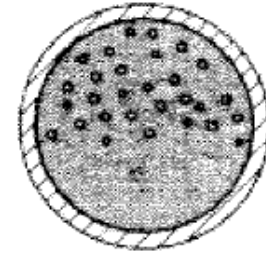
Governing Equations: Fluid flow regimes



A - A
Annular



B - B
Stratified



C - C
Bubbly

- Flow regimes of the fluid inside a tube
 - Two-Phase Lockhart-Martinelli calculations are based on an Annular Flow regime
 - This is a general case in all simple condensers, and a safe assumption



Governing Equations: 2 ϕ Lockhart-Martinelli Calculations



Calculate ϕ , two-phase heat transfer coefficient multiplier.

➤ Lockhart – Martinelli correlation

➤ An empirically formulated two-phase multiplier equation

➤ $\phi^2 = f(X)$

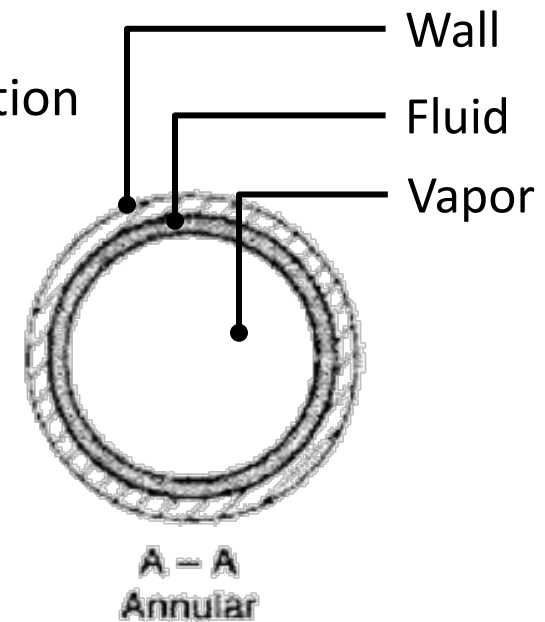
➤ X – Lockhart-Martinelli parameter

$$X = \left[\frac{f_{w,v}}{f_{w,l}} \right]^{1/2} \left[\frac{\rho_l}{\rho_v} \right]^{1/2} \frac{x}{1-x}$$

$f_{w,v}, f_{w,l}$ = Wall friction factor, vapor / liquid

ρ_v, ρ_l = Vapor / liquid density, $\frac{\text{kg}}{\text{m}^3}$

x = Quality



- Lockhart-Martinelli correlation is based upon an annular flow regime.



Background Theory / Governing Equations: 2 ϕ Heat Transfer Calculations



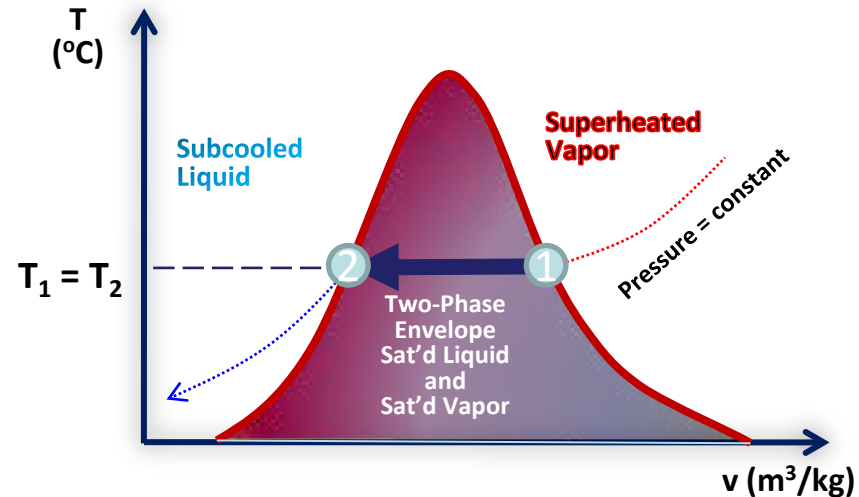
- Solving for the convection value using Lockhart-Martinelli multiplier

$$h_{2\phi} = \phi^{1/2} * h_l$$

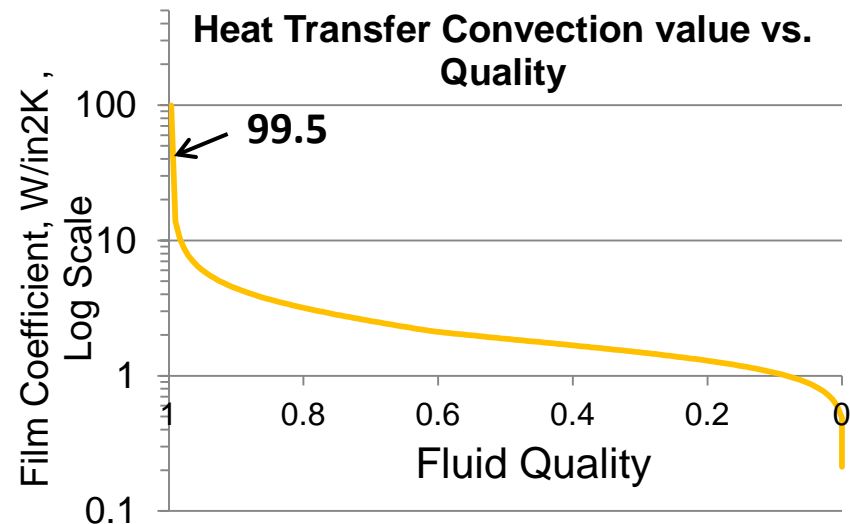
$$G_{2\phi} = h_{2\phi} * A_s$$

$$h_l = \text{liquid phase convection, } \frac{\text{W}}{\text{m}^2\text{K}}$$

$$A_s = \text{heat transfer surface area, m}^2$$

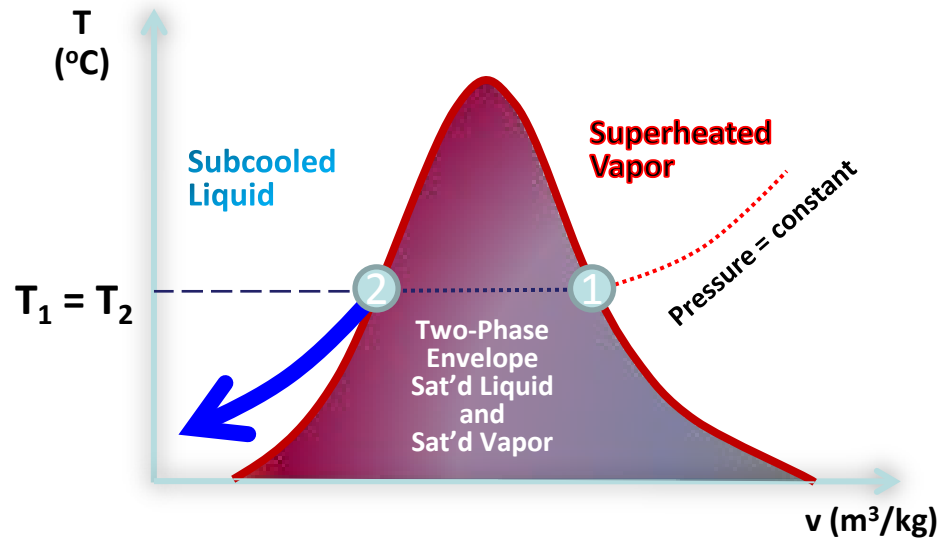
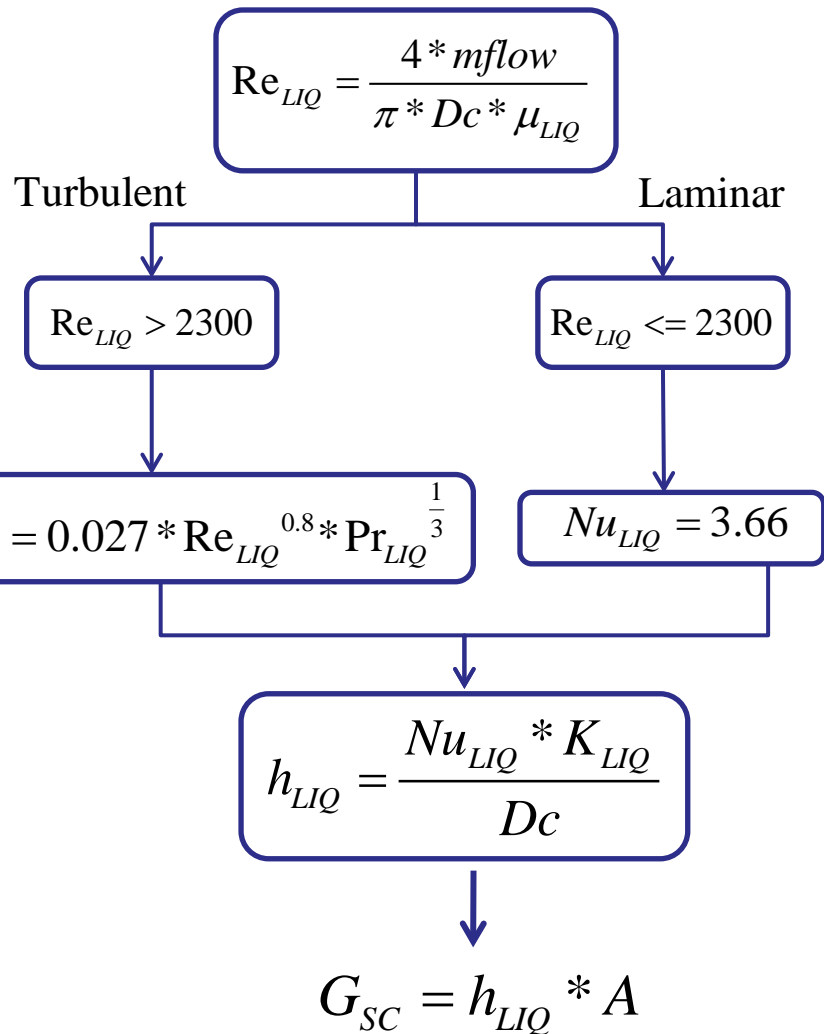


- Thermodynamic Plot highlights the region being analyzed (arrow).
- The plot on the right shows behavior of the convection value in relation to the fluid quality for saturation temperature at -4 degC @ 216W.





Background Theory / Governing Equations: Liquid Phase Heat Transfer Calculations



- Equations here are based upon 1-phase, subcooled liquid. Using the flow characteristics, either turbulent or laminar, the heat transfer coefficient is calculated.
- Thermodynamic plot above shows (the blue arrow) section being analyzed.



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 - DeCoM
- Conclusion
 - Summary





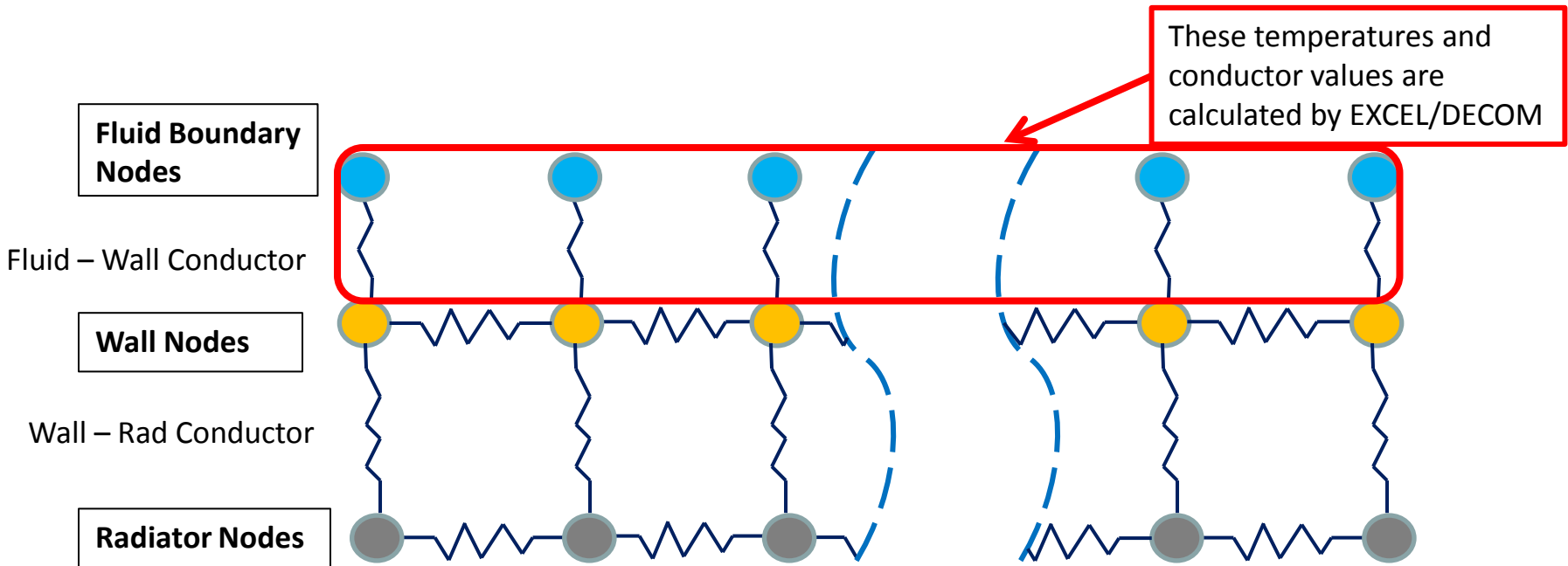
**Equations based on Governing Theory from previous slides.

- DeCoM (Deepak Condenser Model) Implementation

- Code based on FORTRAN language.
- Model works for transient and steady state conditions
 - Response time to transient is part of future work.
- Calculate condenser fluid quality, temperature values, and fluid – wall convection value.
 - Radiator and wall temperatures are calculated by SINDA.
- Input DECOM in VAR 1 of SINDA, in order for the logic to be executed at every time step.



DECOM Implementation: Nodal network



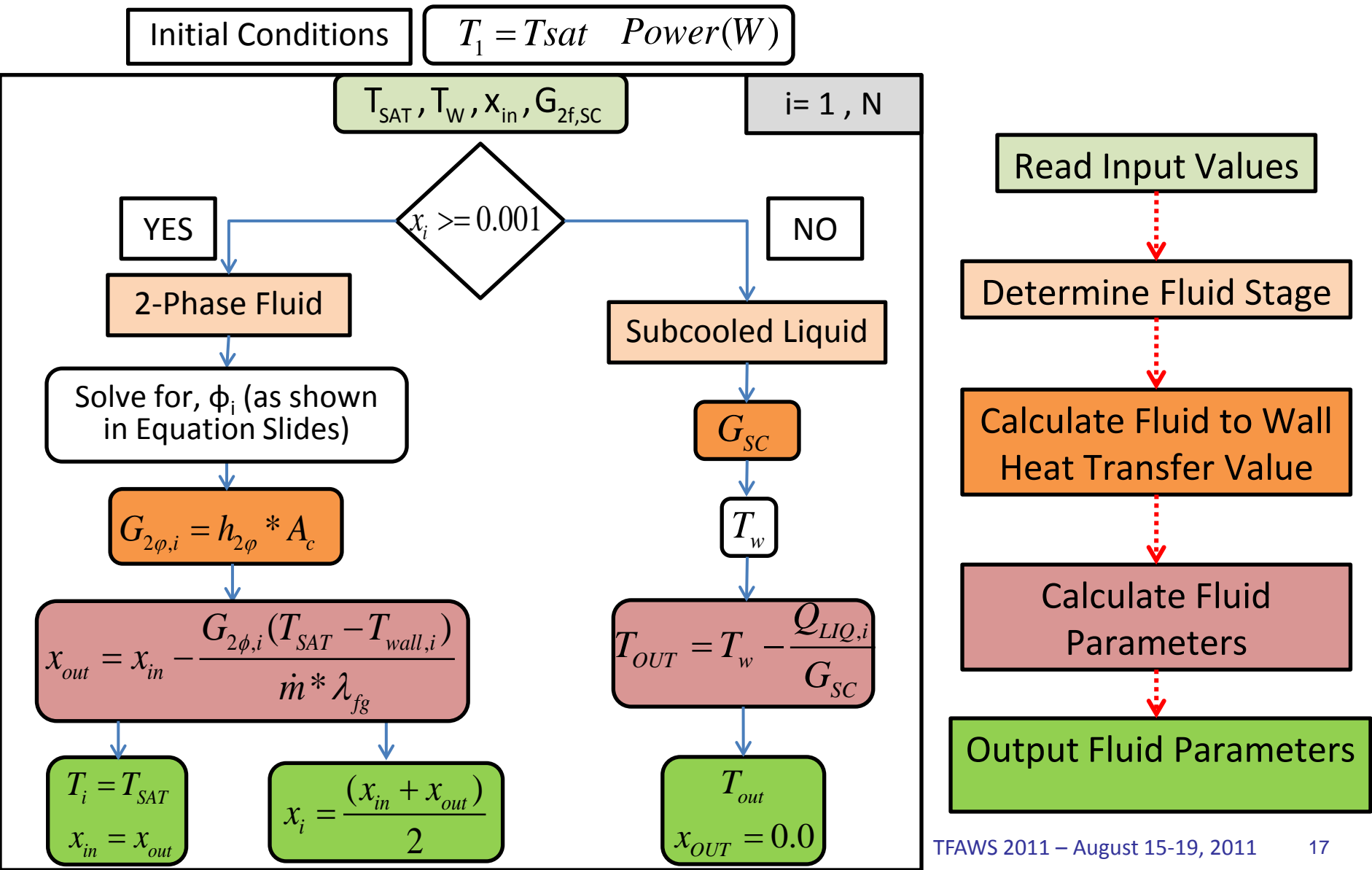
Nodal Network

- **DECOM Internal**

- The above diagram shows the network of nodes in the solution (code).



DECOM Implementation: Calculations Flow Chart





Outline



- Introduction
- Governing Equations
- Develop 1D Computer Code
 - DeCoM
- **Conclusion**
 - Summary





Summary



- Alternative LHP Condenser modeling method
 - Purpose of explicit condenser modeling
- Understand condenser governing equation
 - Implement two-phase correlation method
 - Fluid to Wall interaction modeling
- Developed FORTRAN code based on governing equations.



BACKUP

Symbols & Acronyms



Superscripts

G , Conductance $\left(\frac{W}{K}\right)$

Q , Heat Rate (W)

x , Fluid Quality

T , Temperature (C)

A , Area (in^2)

L , Length (in)

D , Diameter (in)

m_{flow} , Mass Flowrate $\left(\frac{kg}{sec}\right)$

ϕ , Two-Phase
heat transfer multiplier

XM, Lockhart-Martinelli parameter

\sim Approximate

λ , Latent Heat of Vaporization $\left(\frac{J}{kg}\right)$

C_p , Specific Heat Capacity $\left(\frac{J}{kg * K}\right)$

μ , Dynamic Viscosity $\left(\frac{kg}{in * sec}\right)$

k , Thermal Conductivity $\left(\frac{W}{in * K}\right)$

h , Heat transfer coefficient $\left(\frac{W}{in^2 * K}\right)$

Re, Reynolds Number

Pr, Prandtl Number

Nu , Nusslett Number

Subscripts

i , Loop count

L / LIQ, Liquid

V / VAP, Vapor

SAT, Saturation

H, enthalpy

2ϕ , two-phase

Acronyms

SINDA: Systems Improved
Numerical Differencing Analyzer)

FLUINT: Fluid Integrator)

SC: SubCooled

LL: Liquid Line

LHP: Loop Heat Pipe

STOP: Structural-Thermal-
Optical Performance